PASTEURIZATION: OUTLINES OF PROCEDURE AND CONTROL

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Introduction

Milk as secreted by the udder cells of a healthy cow is probably sterile—that is, it contains no micro-organisms capable either of decomposing the milk constituents or of causing disease in the consumer of the milk. But when it reaches the collecting cisterns within the udder, and particularly in passing through the teat cistern and canal into the milking pail or machine, the risk of the milk's picking up deleterious micro-organisms steadily increases. Even when carefully produced under clean farm conditions, milk ready for transport from the farm will certainly contain sufficient bacteria to cause souring after a few hours unless it is kept at a temperature below that at which these organisms, in a nutrient medium like milk, begin to proliferate. Dirty, uncooled milk in a tropical climate may begin to sour within four hours.

That raw milk, and especially bulked raw milk from a number of animals, may also contain micro-organisms pathogenic to man has been clearly indicated in the chapter by Kaplan et al. (page 11). Unless it is certain that the animals providing the milk are perfectly healthy, modern hygiene demands that raw milk before it is consumed, and especially bulked raw milk, must undergo such treatment as to prevent not only its rapid deterioration, but also any risk of its conveying disease to the unsuspecting consumer. The treatment that has been found, as a result of many years of experiment and experience, to be generally most satisfactory for these two purposes, and to cause the minimum of change in the composition, flavour and acceptability of the milk, is the form of heat treatment known as pasteurization. From the hygienic standpoint, effective heat treatment does not necessarily entail the destruction of *all* the micro-organisms originally present, but it must accomplish the destruction of any pathogens, which fortunately are all rather sensitive to heat.

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There are therefore four main problems facing the technical management of any pasteurizing plant, be it large or small, and whatever the particular method of heat treatment used. These are:

(1) to obtain as uncontaminated a supply of raw milk as possible;

(2) to destroy all possible pathogens present in it, and as many as possible of the rather more heat-resistant spoilage organisms, without damaging either its flavour or its nutritional value;

(3) to prevent recontamination of the milk, after its heat treatment, with either pathogens or spoilage organisms;

(4) to prevent, after pasteurization and during the course of distribution of the milk to the consumer, the growth of the small residuum of spoilage organisms that may have survived the heat treatment.

In the present chapter there will be no attempt to give detailed instructions for the operation of pasteurization plants since these can be found elsewhere (see the accompanying Select Bibliography). What is attempted is to present, with a certain emphasis on the hygienic aspects, a brief outline of pasteurization methods, of the various requirements of a pasteurizing centre, of difficulties that may arise in a country or district taking up pasteurization for the first time, and of methods for controlling the efficiency of the process. The important question, affecting the final quality of the product from all types of pasteurization plants, of the initial quality control of milk on reception, and the modern technique for testing incoming milk in relation to its fitness or unfitness for pasteurization, is dealt with in the chapter by Johns (page 223).

Definition of Pasteurization ; Outline of Different Methods

The foregoing paragraphs make some mention of what milk pasteurization should accomplish. In some countries, since effective pasteurization is so important from the health standpoint, the word has been given a precise legal meaning; the temperatures and times of heat exposure required have been exactly defined, and the process is permitted to take place only in an approved plant in officially registered premises. But there are at least six methods, each of which has been used with success, for the effective heat treatment of milk in such a way as to meet public health standards. Some countries have therefore decided not to attempt the thankless task of endeavouring to define these procedures in legislation, but to exercise control solely through the careful, periodic examination of the treated product. Methods are now known, and will be discussed later, by which it is possible to decide whether or not a given sample of presumed pasteurized milk has, in fact, been sufficiently heat-treated to make it safe for consumption.

The six principal methods for effective pasteurization, one or other of which may have special advantage in particular circumstances over the others, are in effect variations on the same theme—namely, that for the heat destruction of micro-organisms with minimum changes in the consumer-value of the milk, the time and temperature of heat exposure are the variables which must be considered together and carefully controlled. The lower the temperature of exposure the greater the time needed; the higher the temperature, the less the time. But as a result of much experiment, the relationship between time and temperature for killing any micro-organisms has been found not to be a simple, straight line, but to follow a curve in which, as the temperature rises, the time needed for destruction falls much more rapidly. If the *logarithm* of the time is plotted on a graph against the temperature, the curve showing this relationship approximates to a straight line. Thus, while about 40 minutes is required to kill the more heat-resistant pathogens in milk at 57°C (134.6°F), about ten seconds only is required at 71°C (159.8°F) and less than two seconds at 75°C (167.0°F). Theoretically there is almost an infinite number of combinations of time and temperature that would be equally effective, from about an hour at 56°C (132.8°F) to a fraction of a second at 78°C (172.4°F). In practice, the principal pasteurization methods referred to add a substantial factor of safety, either of time or temperature of exposure, or both, to the minimum figures required for effective destruction.

The methods are as follows, placed in historical order of development:

1. *The " batch holder " process,* in which milk is heated in a large jacketed container by steam or hot water circulating in the interspace. The temperature to which the milk is to be raised and held varies (in different countries with different ideas of what margin of safety to allow) from not less than 60°C (140°F) to as much as 65.5°C (150°F), for at least 30 minutes. The milk is then cooled, still in the container, to 10°C (50°F) or less. The batch holder vessel has then to be emptied, and there is a break in the operation of at least an hour before the next batch is ready for filling into the distribution bottles or cartons.

2. *The continuous-holding method,* an extension of the batch system, by which the milk is heated (and subsequently cooled) by a plate type of heat-exchanger *outside* the actual holding vessels of which there may be four or more and each of which may have a capacity of up to 500 litres. The heated milk, at say 65°C, is run into the first holding vessel, where its temperature is maintained by a hot-water jacket or other means. When the first holder is full, which takes perhaps 10-15 minutes, the filling of the second holder begins automatically, and so on. By the time the first holder has been held for 30 minutes, the last is just being filled. A virtually continuous flow of pasteurized milk to the bottling apparatus can thus be obtained. Large volumes can be treated in the course of a few hours. The difficulties

of running, and particularly of cleansing, this type of plant are formidable (especially the difficulty of preventing the growth of thermophilic bacteria), and there are now very few plants of this type in use. This method will not be discussed further.

3. "*In-bottle*" *pasteurization,* by which milk is heated to "holder" pasteurization temperatures and filled into special bottles which are then hermetically sealed. The filled bottles are maintained at the holder temperature for at least 30 minutes, and are then cooled rather slowly by immersion or partial immersion in water (or in a stream of cold air).

4. *The so-called "flash" process,* by which milk is heated as rapidly as possible to 75°C (167°F) or 80°C (176°F), or even above, and then cooled rapidly.

5. *The high-temperature, short-time* (HTST) continuous process, by which milk is rapidly brought to a temperature of 71°-72°C (159.8°-161.6°F), is held at that temperature for not less than 15 seconds, and is then rapidly cooled to 10°C or below. These temperatures and time give a good margin of safety, but there are minor variations in them in some countries where times and temperatures of HTST heating are legally defined. Heating is usually by hot water, and the rapid heat exchange is effected through stainless steel plates or, in one type of machine, by passing the milk through the annular space between concentric water-heated tubes. Electrical methods of heating have also been used, in a few cases where current is very cheap and plentiful.

6. *The ultra-high temperature (UHT) continuous process,* by which milk is rapidly heated, usually in two stages (the second stage being under pressure), to between 135°C (275°F) and 150°C (302°F) for times of the order of a few seconds only, and is then either cooled rapidly and bottled as aseptically as possible, or bottled hot (at 75°-80°C).

Each of the above six methods, which are placed in the approximate order of their invention over the past fifty years, has been used at different times and in different countries. For each method there are several different makes of plant with minor variations in method of operation. The minimum times and temperatures legally laid down in the different countries may also vary, but the combination of time and temperature must, in each case, be sufficient to destroy, with a good margin of safety, the tubercle bacillus, *Mycobacterium tuberculosis,* which appears to be the most heat-resistant of all the pathogens which may occur in raw milk. The Q-fever organism, which is occasionally present in raw milk, has a heat-resistance of the same order, but is reported to be destroyed by the time and temperature normally used in the HTST process, and also by exposure in the holder process to 63°C (145.4°F) for 30 minutes.

The dairy machinery expert might say that of the six categories of heat treatment described above, only numbers 1, 2, 3 and 5 are true pasteurization

processes; the others, numbers 4 and 6, should be differently described. Number 6 is, in effect, a sterilization rather than a pasteurization method, and will not be considered further here, although it might be mentioned that after a lengthy experimental stage, two at least of the modifications of this process are growing in industrial importance, and in the course of time, when adequately trained technical staff are available, are likely to be very widely used (see the chapter by Galesloot, page 269).

Planning a Pasteurizing Dairy

The first requirement is not merely a supply of raw milk, but an adequate supply of raw milk of pasteurizable quality. Where, in a technically underdeveloped country, a new pasteurization centre is to be set up, this requirement may be very difficult to fulfil, particularly in a warm climate and where production hygiene may be non-existent. But even under such conditions, if milk is collected very soon after milking and rapidly cooled to 6°C (43°F) in a small cooling plant, which may be established to serve a group of peasant producers, the milk can thereafter be transported in bulk, or in cans surrounded by broken ice, for fairly long distances without developing sufficient acidity to become impasteurizable, and thus preventing a hygienic product from reaching the consumer. The thermal capacity of milk is high, and to raise cooled milk in cans, or in tankers, to a temperature where souring bacteria begin to proliferate requires a surprisingly large influx of heat. Cooled milk in the smaller containers in which milk is usually distributed heats up much more quickly. It is desirable, therefore, that the pasteurizing dairy be situated close to the milk consumption area, rather than in the production area.

In siting a new pasteurization centre, the distance that milk supplies have to be transported, together with the range of atmospheric temperatures experienced in the region in question, will determine whether or not cooling centres are needed in the production areas. Some regard will also have to be given to transport difficulties at different seasons of the year.

It is more likely that the necessary services will be available if a pasteurizing dairy is sited close to a centre of population than if it is sited in a remote area. These services include: (*a*) a constant supply of water of good hygienic quality; (*b*) an adequate supply of fuel for steam raising (the steam requirements of a pasteurizing plant, where, in addition to effecting the heat treatment of the milk, cans and bottles have to be cleansed, are considerable); (*c*) an adequate supply of electric current; (*d*) a sufficient system of all-weather roads and by-roads in the distribution area. Milk hygiene is the first to suffer if one or other of these services is defective. It may well be necessary, from the beginning, for the dairy itself to provide one or both of the facilities (*a*) and (*c*) above. If so, markedly increased capital expenditure is obviously entailed, and additional staff will be needed.

The dairy site should be large enough to provide not only for the dairy building itself, for ample storage and cold-storage space, for an adequate boiler-house and room for vehicles, but also for future expansion, including an adjacent space for a building to house, if need be, a milk-manufacturing plant. As regards the dairy building itself, the same principles apply, of providing what may appear to be rather more than adequate space. Poor planning at the start, and parsimony in space within the building, ultimately exact their toll either on the quality, not least on the hygienic quality, of the pasteurized milk or in staffing difficulties. Planning must ensure adequate space not only for the pasteurization equipment and its servicing, but also for raw milk storage, for its clarification or filtering, for filling, capping (or sealing) and crating the final containers, for storage of pasteurized milk in bulk, for bottles and can-washing machines with plenty of room for access to them, for office purposes, and for what is a prime necessity if efficiency of operation and a hygienic product are to be maintained—a properly equipped laboratory. Finally, but of major consequence in any country, whatever its state of technological development, well-trained and competent plant operatives are necessary.

Choice of Pasteurization Technique

Different methods of pasteurization have already been briefly outlined. A choice of one or other has to be made, together with a decision as to the type of final container—bottle, carton or possibly a larger vessel (if, as is the case in certain warm countries, pasteurized milk is most conveniently distributed, at small distribution centres, direct from cans or bulk containers into the clean vessels brought by consumers to the centres).

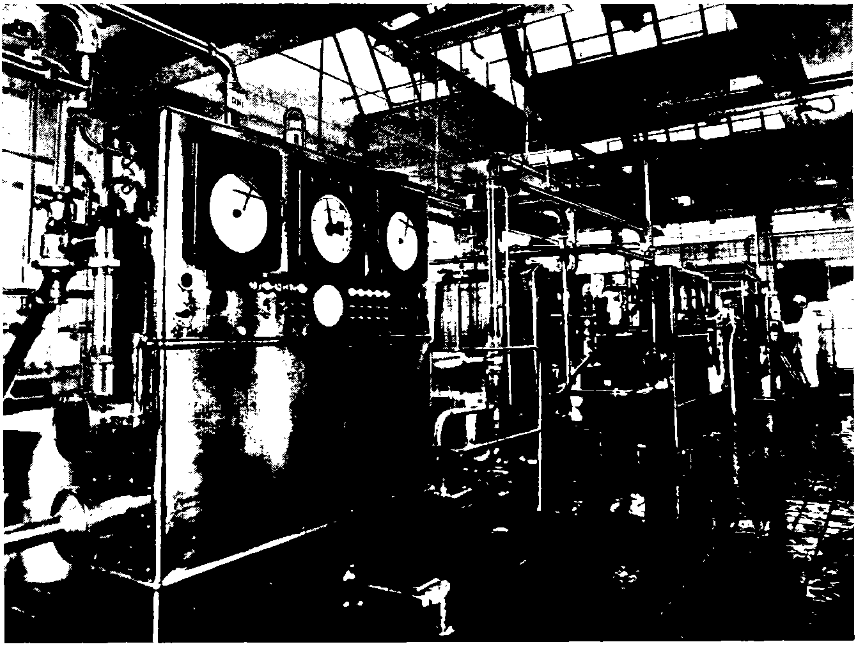
The volume of the actual, and that of the prospective, available milk intake have to be taken into account in deciding which type of pasteurization plant to install, but let it be stated forthwith that some form of HTST pasteurization is at present the principal method for the heat treatment of milk in the large majority of processing dairies, both in most of the technologically advanced and in many of the less advanced countries. Nevertheless, the batch holder is still in use in some centres where relatively small quantities—say up to 500 litres per day—are to be heat-treated, and the larger-capacity, continuous holder is not yet completely extinct. In-bottle pasteurization, despite its ability to provide a product immune, or almost immune, from the risk of post-pasteurization contamination, has never been very popular, mainly on account of its initial cost, the large and cumbersome nature of the plant, and the cost of operation, but a small, declining number of plants of this type is still in operation.

The advantages of the HTST process over the holder or over the in-bottle method are as follows: (*a*) for the same daily output of pasteurized milk the initial cost of the HTST pasteurization equipment is less than that

required for either of the other methods, and the day-to-day operating costs are lower; (*b*) the area of floor space required for the HTST equipment is much less, and the plant can be increased or diminished in pasteurizing capacity with changing requirements much more easily than with the other methods; (*c*) pasteurized milk is being produced and is ready for bottling within two or three minutes of the commencement of operation, whereas with the holder plant, or with the in-bottle plant, the time required is about an hour; (*d*) the HTST equipment, being smaller and capable of being cleansed by modern methods of detergent circulation, requires less labour to keep it in a satisfactory hygienic condition; (*e*) very much larger quantities of milk per hour (up to 20 000 litres or more) may be pasteurized by the HTST method, in a plant of reasonable size, than by the holder or in-bottle methods.

Further, the modern HTST equipment is fitted with a number of automatic control and precautionary mechanisms which render it almost fool-proof, provided that these mechanisms are kept in good order by a reasonably skilled technician. Owing to the " regenerative " process by which the cold incoming milk cools down, and is itself partially warmed by the hot pasteurized milk by rapid heat transfer through thin, stainless steel plates, the apparatus is economical in its steam requirements. The milk warmed in this way passes on to be further heated to the correct pasteurization temperature by circulating water only a few degrees hotter than the milk. The milk is

HTST PASTEURIZING APPARATUS



held at that temperature for not less than 15 seconds by passing it through a pipe of the requisite length. A rapidly acting flow-diversion valve, thermostatically controlled, at the end of the " holding " pipe prevents any milk which has not reached the pasteurization temperature from getting through to the bottling apparatus. Correctly heated milk, passing this valve, is quickly cooled, first by the incoming milk, as just described, and then by brine or chilled water, down to about 3°-5°C (37°-41°F). It can then either be run direct into the bottling or cartoning apparatus (non-returnable hygienic cartons are being increasingly used in many countries) or stored in large insulated containers at this low temperature until required for distribution. Properly pasteurized HTST milk in cartons or bottles should have a keeping quality of not less than 24 hours at 18°C (64°F). The figure shows HTST pasteurizing apparatus with the control panel in the foreground.

Why not boil?

The question has frequently been asked as to why milk should be *pasteurized*—a process requiring rather elaborate machinery and margins of safety that may appear unnecessarily small—instead of being heated to boiling-point or very close to it at the dairy, a process that will, with a very large margin of safety, kill all micro-organisms that are not present in the form of spores. The answer, briefly, is that boiling causes changes in flavour that are disliked by many consumers, causes pronounced physical changes and also some loss of nutritional value, destroys the "cream line", is technically difficult on a large scale, and is commercially uneconomic.

" *Cream line* "

The " cream line ", indicating in easily visible form the amount of fat which has risen to the top of a bottle of milk, is regarded as of importance by many consumers in giving information on the compositional quality of the milk. The housewife not infrequently pours off the " top of the milk " to serve with fruit or cereal. (The depth of the cream line has nothing to do with *hygienic* quality.) In whole milk correctly pasteurized by either the holder or the HTST process (but not in milk heated by the " flash " process), a good cream line should develop, but if the normal pasteurization temperatures have been exceeded, the pasteurized product may either give no cream line or need to be held for a long time at a fairly low temperature before a rather poor " line " appears. The HTST process correctly carried out is perhaps a little more destructive of the cream line than is the batch holder process, but in any case the depth of the cream line or the speed with which it is formed is no more than a dubious criterion of milk quality. Thus by diluting milk with water up to about 50 % dilution, an increasingly clear cream line is obtained.

" Flash pasteurization " plants usually take milk far above the HTST temperatures, with complete loss of cream line. The "flash" method is thus

more popular in countries where cream line is unimportant and a cooked flavour is not objected to. The loss of nutritional value due to the flash process is fortunately small.

Milk may be "*homogenized*", a process which breaks up the fat globules into much smaller particles that do not rise to form a fat layer. Pasteurized homogenized milk is a commercial product in several countries. When fresh, it has a richer flavour than ordinary pasteurized milk, but the greatly increased surface area of the fat particles renders it more susceptible to post-pasteurization deterioration. From the hygienic standpoint it may be regarded as the equivalent of ordinary pasteurized milk.

Pasteurizing twice

There is no good reason, if considerations of extended keeping quality or of hygienic safety require it, why milk should not be pasteurized twice. There may be further loss of cream line and some slight deterioration in flavour, but the effect on the nutritional value of the milk is virtually negligible. Minor changes in the vitamin content of the milk are brought about by any form of pasteurization (see the chapter by Galesloot, page 269).

Control of Pasteurization

Since the effectiveness of pasteurization has important public health implications, the question of adequate control of the process needs careful consideration.

Control should be exercised (*a*) by the dairy itself, where arrangements are normally made for the routine testing of both incoming and outgoing milk and of the efficiency of each stage of the process; and (*b*) by the public health or sanitary authority, one of whose main duties is to protect the public against the risk of disease.

As regards *control by the dairy*, it is obvious that this cannot be exercised unless there is a suitably equipped laboratory and a laboratory staff with a command both of the chemical and of the bacteriological techniques required, duly supported by a manager who understands the functions of a laboratory in a processing dairy.

In addition to the testing of incoming milk for bacteriological and compositional quality the control duties of the dairy embrace the assessment of the state of cleanliness of the pasteurizing plant itself (and not least that of the bottle-filling and capping machines), of the cans and tankers before they go out to milk producers or collecting depôts, and of the bottles or other containers before they are filled with pasteurized milk. These latter duties entail controlling the efficiency of the can-washing and bottle-washing machines, the quality of the detergents used, the concentration and efficiency of sterilizing agents, and the bactericidal activity of the rinse water. The quality and composition of the incoming water supply are important points

for the dairy laboratory to examine; at the other end of the processing chain, the efficiency of the disposal of dairy wastes usually needs laboratory attention. A check-up, at intervals, of the automatic controls on the dairy plant should also be a laboratory task.

The primary duty of the dairy control laboratory, to which all the duties just mentioned are important subsidiaries, is the control of the quality of the outgoing milk. Regular testing is essential; daily or twice-daily phosphatase tests for efficiency of pasteurization, the methylene blue or some similar test for keeping quality, the coliform test for post-pasteurization contamination.

In the better-equipped laboratories, a periodic, detailed bacteriological examination of the pasteurized milk as it leaves the dairy will usually give valuable information on possible sources of trouble. Details of the various tests used need not be given here (see accompanying Select Bibliography). For present purposes it is enough to say that the phosphatase test is based on the fact that efficient pasteurization is just sufficient to destroy this easily recognizable enzyme. If the presumedly pasteurized milk has been inadequately heated, or if small amounts of raw milk have got through into the final product (for example, by leakage across a plate in the pasteurizing apparatus), a detectable quantity of the enzyme will be found in that product. The methylene blue test, a similar dye test, or the clot-on-boiling test appropriately carried out will give a shrewd indication of the probable keeping quality of the pasteurized milk. The coliform test depends on the fact that properly conducted pasteurization destroys this group of easily recognizable organisms. If, for example, coliform bacteria are not found in milk direct from the pasteurizer, but are found in the bottled milk, then post-pasteurization contamination, which may be—and in certain countries will be—dangerous, is occurring. Its origin must be found and the trouble remedied.

As regards *control by the public health or the licensing authority*, tests will usually be made of samples taken by the inspector at any stage from the pasteurizing plant to the consumer. The tests are usually similar to, though less frequent than, those effected by the dairy itself, and they must be no less searching. One test which some public health authorities still carry out on pasteurized milk is the guinea-pig test for the presence of living tubercle bacilli. But since the repeated finding that a negative phosphatase test is never accompanied by a positive guinea-pig test, the frequency of application of the latter test (which is one that needs particularly expert supervision if the results are to be of any value) is today much less than it was formerly.

In addition to marking the tests on the product, many sanitary authorities visit the pasteurization plant at irregular intervals and without previous warning, to inspect the thermograph records, the position and accuracy of the thermometers, the presence or absence, and the position, of the automatic safety devices, the presence and position of cocks for sampling milk

at different stages during pasteurization, and also the state of cleanliness of the plant, the buildings and the surrounding premises—the last being of major importance in warm countries, where dust and flies may abound. It need hardly be said that such inspection should be carried out scrupulously by a competent officer of the licensing authority, and action taken without delay if any defect is found. (Control of the health of operatives in the pasteurizing dairy is dealt with in the chapters by Cockburn and Vladimirov, pages 531 and 537.)

Conclusion

Pasteurization has been described as " the process of heating milk to such temperatures and for such periods of time as are required to destroy any pathogens which may be present, whilst causing minimal changes in the composition, flavour, and nutritive value ".

One can legitimately add to this " and to increase the keeping quality so that sufficient quantities of wholesome milk may be supplied to large populations, in urban centres and elsewhere, who would otherwise not be able to enjoy the nutritional benefit of such a supply ". It is not always realized that both aspects in the above description are of comparable significance from the standpoint of human health.

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